PROMOTING DISRUPTIVE MILITARY INNOVATION: Best Practices for DoD EXPERIMENTATION and PROTOTYPING PROGRAMS

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The Department of Defense (DoD) has recently launched several initiatives to accelerate technological innovation and sustain the U.S. military's technological leadership in an environment of increasing global competition. These include six new or expanded programs to enhance the use of experimentation and prototyping under the Office of the Secretary of Defense and the military services. This study examines the six programs and compares their features in light of historical case studies of past disruptive military innovations and the success factors that enabled these innovations to progress from idea to prototype to fielded military capability. Best practices are identified that can be shared between the six programs, or implemented in the design of new DoD initiatives to promote and secure U.S. technological dominance on the battlefields of tomorrow.

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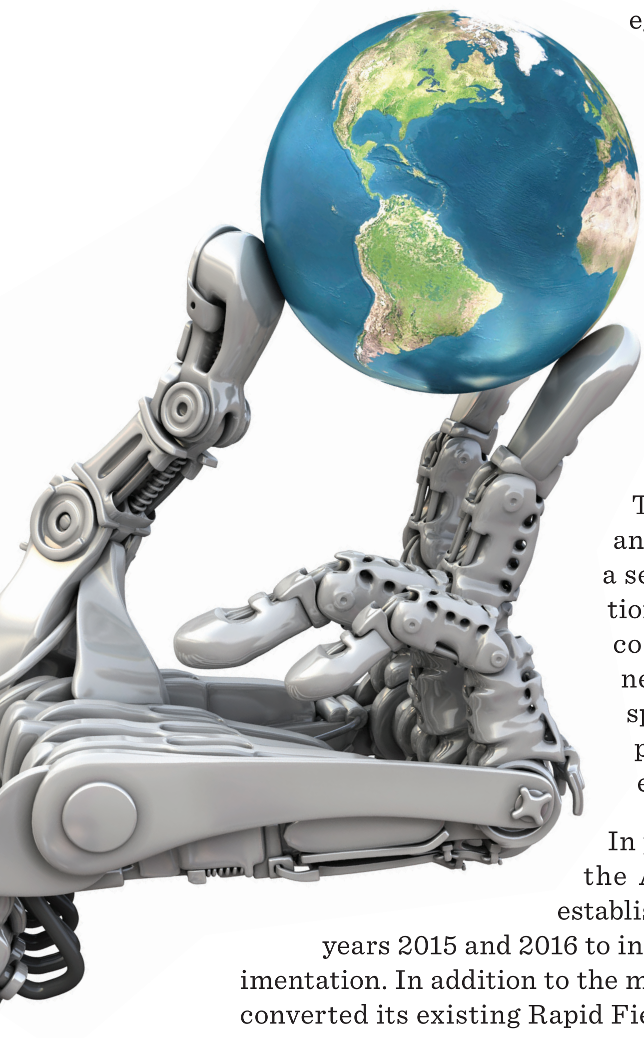
The American way of war is based on the technological superiority of the armed forces of the United States. Technological overmatch in combat capability depends on the nation's abilities to develop disruptive innovations that change the character of war and then to translate those innovations into fielded military capabilities.

In autumn 2014, the Secretary of Defense noted that global competitors are rapidly eroding U.S. dominance in key warfighting domains, and U.S. defense budgets were likely to continue to tighten. He called for a Third Offset strategy to use innovation to enable sustained U.S. military-technological superiority (Hagel, 2014). The Third Offset recalls two prior offset strategies: the early Cold War strategy of using nuclear deterrence to counter Soviet numerical advantages in Europe; and the fielding of advanced conventional weapons technologies, such as precision guided munitions and battlefield networking, to achieve overmatch in the 1980s–1990s. The Secretary also announced the Defense Innovation Initiative (DII) to accelerate Department of Defense (DoD) innovations to advance the Third Offset strategy (DoD, 2014). At about the same time, the Under Secretary of Defense for Acquisition, Technology, and Logistics, USD(AT&L), announced Better Buying Power (BBP) 3.0, a set of policies to encourage DoD innovation and technical excellence, and achieve cost efficiency in developing and fielding new defense capabilities (DoD, 2015). It specifically aimed to "increase the use of prototyping and experimentation" to accelerate innovation.



In parallel with these strategic initiatives, the Army, Navy, Air Force, and Marines established or expanded programs during fiscal years 2015 and 2016 to increase the use of prototyping and experimentation. In addition to the military services' programs, USD(AT&L) converted its existing Rapid Fielding Office, which had served to meet urgent equipment needs in the Iraq and Afghanistan conflicts, into a new Office of Emerging Capabilities and Prototyping (EC&P). Also, the Strategic Capabilities Office (SCO) had recently been established as an independent defense agency to conceptualize and demonstrate novel military capabilities enabled by technology. These six new programs listed in Table 1 have taken unique approaches to the experimentation and prototyping challenge.

TABLE 1. LIST OF THE SIX DOD EXPERIMENTATION AND PROTOTYPING PROGRAMS ASSESSED

• U.S. Army: Technology Maturation Initiative (TMI), plus Army Expeditionary Warrior Experiment (AEWE) and other activities
• U.S. Navy: Office of Rapid Prototyping and Experimentation (RPED)
• U.S. Marine Corps: Participation in RPED, and Marine Corps Warfighting Laboratory (MCWL)
• U.S. Air Force: Strategic Development Planning and Experimentation (SDPE) Office and related Development Planning activities
• Strategic Capabilities Office (SCO)
• Office of the Deputy Assistant Secretary of Defense, Emerging Capabilities and Prototyping, DASD(EC&P)

Most recently, Congress announced in the National Defense Authorization Act of 2017 that USD(AT&L) would split to create a new Under Secretary of Defense for Research and Engineering, USD(R&E), distinct from the Under Secretary of Defense for Acquisition and Sustainment, USD(A&S), to further accelerate innovation and to oversee experimentation and prototyping activities. Senior DoD leaders are currently designing the strategies and business practices for the new office. This is a historic opportunity to use the lessons from past defense technology innovation and the experience of the six programs to redesign the DoD's experimentation and prototyping practices for the success upon which future U.S. defense competitiveness depends.

This study aims to uncover and articulate those lessons to inform the policymakers and acquisition practitioners designing the new practices. It will address three questions:

- What factors have driven success for earlier disruptive defense technologies?

- What aspects of the six programs should be adapted by the others to improve their effectiveness?
- How should the DoD manage its growing experimentation and prototyping efforts to best accelerate defense innovation and speed the translation of promising innovations into operational capabilities?

The analytical approach encompasses:

- Case studies of past disruptive military innovations in order to clarify the challenges they encountered in development and the success factors that enabled them to progress from initial concept or discovery to fielded capability;
- Analysis of the six programs, based on interviews with their leadership, to detail their similarities and differences, assess their relevance to the challenges and success factors identified, and identify transferable best practices; and
- Synthesis of specific recommendations to incorporate the most innovative and promising into the design of both new and existing defense experimentation and prototyping programs.

The Lessons of Past Disruptive Military Innovations

Key data from case studies of 17 military technologies that were successfully introduced during a 100-year period from the end of the 19th century to the end of the 20th are summarized in Table 2. These are widely regarded disruptive technologies that significantly changed the character of military operations, rendering obsolescent the military systems and practices that predated or failed to incorporate them.

In each case the pathway is divided into two distinct stages: (a) the path from idea to fully working prototype, and (b) the subsequent path from prototype to adoption and fielded capability.

In 12 of the cases, the prototype was developed as a bottom-up innovation without a formal requirement or program motivating the effort. As such, the technologies came largely as a surprise to strategic military decision makers and without high-level encouragement. In five of the cases (the tank, the nuclear weapon, the anti-aircraft guided missile, the communications satellite, and Global Positioning System), the prototype was a response to a "top-down" strategic requirement.

In each case, the path from prototype to military capability involved complementary changes to Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities and Policy, commonly abbreviated as DOTmLPF-P. This is not a success factor so much as a universal requirement. The success factors for the second stage of the pathway helped enable the required institutional adoption of the prototype and generation of the complementary DOTmLPF-P innovations.

The cases suggest that common success factors exist for each of the two stages that are relevant across different classes of technology and different times. Not all the success factors are required in all cases. Indeed, some are mutually exclusive. But all of the successful cases exhibit one and typically more common factors.

From Idea to Prototype

Four success factors emerge from the first stage—the path from idea to prototype.

1. The prototype leveraged a substantial amount of mature technology—the innovation was based on a novel component or novel combination of existing components, but not an entirely new conception.
2. The effort was self-funded (or funded out of a standing research budget), and thus did not require selling the idea to outsiders to get to a full working demonstration.
3. The effort was promoted or approved by a small, special-interest military community.
4. The effort was the result of a top-down military requirement.

The first factor addresses *technological maturity*, while the others address *sponsorship*. Regarding maturity, nearly all of the successful prototypes (14 of 17), including all that emerged from bottom-up innovations, were distinguished by employing only a critical new component, or a novel combination of existing components. The successful prototypes were built at just the moment when the underlying technologies were mature enough to work together reliably in a demonstration.

TABLE 2. SUMMARY OF HISTORICAL CASE STUDIES OF DISRUPTIVE MILITARY TECHNOLOGY INNOVATION

Military Innovation	First Implementation	Inventor(s)	Approximate Year of Introduction	Path to Working Prototype	Translation from Prototype to Fielded Capability
Turbine Propulsion	*Turbinia* (ASME, 1981)	C. Parsons	1897	Parsons steam turbine used for electrical generation, adapted for propulsion by adding propeller shaft as a personal company-funded prototype by Parsons (1, 2)	Prototype vessel demonstrated at Queen Victoria's Diamond Jubilee naval review; public sensation led to use in two destroyers within 2 years (1)
Submarine	*Holland VI*; multiple other contenders (Van der Vat, 1995; Parrish, 2004)	J. Holland, T. Nordenfelt, G. Zede, others	1897 (*Holland VI*)	Many incremental prototypes to realize an ancient concept; sporadic funding by various navies. Several contenders for title of first true submarine (1, 3)	Small communities of naval innovators procured and tested; significant doctrinal/ethical debates until 1914 WWI combat successes (4, 5)
Airplane	Wright *Flyer* (Chenoweth, 2002)	W. Wright, O. Wright	1903	Self-funded research, development, and full-scale flying prototype by Wright brothers (1, 2)	Trials at Fort Myer by the U.S. Army Signal Corps. Slow uptake by early adopters in the Signal Corps and in Europe as an observation platform. Other companies more successful at advanced development (1, 5)
Tank	Little Willie (Fletcher, 1984; Tucker, 2004)	W. A. Tritton, Royal Naval Air Service Lt W. G. Wilson	1915	One of several contracts by Landships Committee (formed by W. Churchill) to develop prototype trench-crossing vehicle (1, 3, 4)	After prototype demonstration, project was transferred to Army; Mark I produced by Tritton's company; doctrine developed in WWI combat (1, 2, 3, 4)
Ballistic Missile	A-2 (Dornberger, 1954)	W. von Braun, others	1934	German Army sponsorship of von Braun research, based on R. Goddard's earlier U.S. work. A-2 was first successful prototype (1, 2)	After viewing films of advanced prototype tests in 1943, Hitler unilaterally authorized full production and use of the full-scale V-2 (1, 2, 3, 5)
Radar	Lab prototypes at U.S. Naval Research Lab (NRL) and elsewhere (Guerlac, 1987)	A. H. Taylor, L. C. Young, R. M. Page; others in parallel	1934	Independent work in several countries and prototype demonstrations within a few months in 1934–35, most under military sponsorship. (1, 2)	At NRL, full-scale prototype demo in 1936 resulted in large-scale funding; in the United Kingdom, rapid deployment of a coastal early warning network in 1937 (1, 2)
Jet Aircraft	He178 (Kay, 2002)	H. von Ohain, E. Heinkel; F. Whittle	1939	Company-funded prototype based on von Ohain research at Heinkel. Parallel engine research by F. Whittle et al. in the UK (1, 2)	On-and-off support from German government for jet aircraft, eventually resulting in Me-262 (2, 3)
Cruise Missile	Fi 103 (Irving, 1973)	F. Gosslau, R. Lusser	1942	Earlier research projects in WWI under Kettering, Sperry; private-funded prototyping by team of corporate developers in Germany (1, 2)	Luftwaffe Gen. Erhard Milch recognized the prototype's technical maturity in 1942 and sponsored advanced development and production as the V-1 (2, 3, 5)
Shoulder-Fired Anti-Tank Rocket	Bazooka (Skinner, 1944)	C. Hickman, L. Skinner, E. Uhl	1942	R. Goddard's original idea of tube-launched rocket tested in 1918 with C. Hickman; combination with shaped charge at Indian Head MD with small Army budget (1, 2)	Demo during Aberdeen test of shaped charge antitank mortars in front of Army and War Department leadership led to immediate production of military version in 30 days (1, 2)
Nuclear Weapon	Trinity test "gadget" (Rhodes, 1986)	R. E. Oppenheimer and many others	1945	Theoretical proposal by A. Einstein and others prompted massive development program, leading to full-scale test (3, 4)	Two militarized prototypes dropped in combat weeks later. Started Cold War arms race, nuclear enterprise and doctrine development (1, 2, 3, 5)
Antiaircraft Guided Missile	Test versions of Nike Ajax and Ground-to-Air Pilotless Aircraft (GAPA) (U.S. Army Center of Military History, 2009)	Many at Bell Labs (H. W. Bode et al.), and Boeing	1947	Research by Germany during WWII; U.S. Army Chief of Ordnance requirements in 1945 led to concept study by Bell Labs, and parallel effort at Boeing (1, 4)	Combination of missile technology plus radar and radio guidance conducted by team of military arsenals and defense firms, with high-level military sponsorship (2, 3, 4)
Communications Satellite	SCORE (Thompson & Thompson, 1999)	Advanced Research Projects Agency (ARPA)	1958	Concept by Arthur C. Clarke (1945). First project by the newly created agency, an integrated military-led effort to demonstrate active satellite communications in 6 months (3, 4)	After success, rapid follow-up by Army (Courier 1B) and joint government-industry teams (Telstar) – led by AT&T and partners, and in service by 1962 (1, 3)
Global Positioning System (GPS)	Transit (Easton and Frazier, 2013)	Johns Hopkins Applied Physics Laboratory (W. Gueir, G. Waffenbach et al.)	1960	Concept developed shortly after Sputnik launch; prototype satellite launches under ARPA sponsorship for nuclear submarine navigation needs (3, 4)	Decades of use of Transit system led to transformative upgrade to modern Navstar Global Positioning System (GPS) (real time, portable receiver, greater accuracy) starting in 1978 (2, 3, 5)
Surveillance Drone	Ryan Firebee (Model 124) (Wagner, 1982)	Ryan Aeronautical Company (S. Schwannhauser et al.)	1963	Ryan proposed addition of photo reconnaissance package to its existing aerial target drone; $200k prototype award following loss of Gary Powers' U-2 (1, 3)	With advocacy from AF Reconnaissance Office, Big Safari program funded operational development and operational reconnaissance programs; status as a special program inhibited larger uptake (2, 3, 5)
Laser-Guided Bomb	Paveway I (deLeon, 1974; Spires, 2005)	Texas Instruments (W. Word, T. Weaver et al.)	1965	Concept jointly advocated to Eglin armaments lab by Word and Air Force Col Joe Davis, securing $100k and 6 months for prototyping effort (1, 3)	Reliable and simple, the prototypes beat out competing electro-optical concepts and found immediate use in Southeast Asia precision bombing (1, 2, 3)
Night Vision Goggles	Gen 2 (wearable) (Wiseman, 1991; Work, 2016)	V. Zworykin and decades of incremental progress	1970	Prototypes existed since late 1930s, growing out of TV, but large, unreliable, requiring external illumination; by 1970s, more miniaturized wearable items were near-COTS (Commercial-Off-the-Shelf) (1, 2)	Army conscious decision to "own the night" as part of 2nd Offset, accelerated technical development, but more importantly Concept of Operations (CONOPS), training, etc. (3, 4)
Surveillance Drone	Amber (Whittle, 2014)	Leading Systems (A. Karem)	1990	Amber, sponsored by DARPA, was an evolution of early Israeli designs such as the Pioneer, used experimentally by the Navy in the Gulf War (1, 3)	Amber was expanded into a militarized version called Predator, which showed its value to military leaders in the Balkans' operations of the mid-late 1990s (1, 2, 3)

Note. Numbers in parentheses refer to the identified success factors observed in the given part of the respective case study.

Regarding sponsorship, eight of the efforts were self-sponsored using private funds or funding from a standing research budget, such that no outsiders had to be convinced that the idea could work before a working prototype could be developed. This was the norm for military inventions prior to the end of World War II. Seven were funded by proponents—often technically specialized organizations—within unique parts of the military that had considerable budgetary autonomy. The submarine and the tank benefited from these visionary communities in the pre-WWII era, and this kind of funding for early development became more common during the Cold War. On the other hand, the first nuclear weapon, the first practical anti-aircraft missile, and the first communications satellite demonstration were complex system of systems innovations involving multiple new technologies and new concepts of operation. They were all sponsored by high-level strategic initiatives that sought to advance military options in areas of strategic importance.

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The cases imply that bottom-up military innovation benefits from the ability to advance a concept to the working prototype stage without needing to convince military stakeholders, except perhaps for a specialized technical community, of its merit. Encouraging most disruptive innovation means enabling innovators to develop ideas that address military problems and prepare prototypes that can prove their claims. The exceptions are the complex system of systems innovations like nuclear weapons and space flight, which have been successfully sponsored by using strategic, top-down approaches led by visionary senior leaders.

From Prototype to Military Capability

The historical cases exhibit combinations of the following five success factors that enabled technologies to progress from a prototype to become military programs and ultimately deliver transformational fielded capabilities.

1. The prototype performed a convincing demonstration before key stakeholders, including high-level decision makers.
2. The technology was brought forward based on the urgency of an active or imminent military conflict (the existence of a conflict was a critical ingredient).
3. The effort had a strong champion within the military community, which could swing opinion in favor of the innovation or defend it from critics.
4. The technology reached a "tipping point," where steady progress finally made practical a capability that military stakeholders already desired or anticipated.
5. The capability was developed within a special community insulated from the need to satisfy a wide range of stakeholders.

A pivotal demonstration before the eyes of key military stakeholders earned many of the innovations broad military buy-in. For instance, John Parson's *Turbinia* turbine-powered 100-foot prototype boat surprised the assembled Navy brass and royalty at Queen Victoria's Diamond Jubilee naval review in 1897, flying between the lines of battleships and cruisers at 34 knots and creating a sensation that led to immediate orders for two turbine-powered destroyers. By 1906, the *Turbinia* prototype had yielded the revolutionary turbine-powered *HMS Dreadnought* (American Society of Mechanical Engineers, 1981). The Wright Brothers brought their *Flyer* to Washington DC to conduct demonstrations at Fort Myer, within view of the White House and the Capitol, after which they received orders from the Army Signal Corps (Chenoweth, 2002). The prototype bazooka was brought to Aberdeen Proving Grounds as a last-minute addition to a 1942 trial of anti-tank mortars. The radical weapon's ability to hit a moving tank, both when fired by its developers and subsequently when fired by generals in attendance, led to an immediate production contract (Skinner, 1944). These kinds of high-profile demonstrations were a powerful means of aligning high-level institutional support behind a radical innovation—sometimes within a single day. Their use has declined over time, though even more limited demonstrations that gave military users exposure to prototype systems helped advance more recent innovations such as laser-guided bombs and early Predator drones.

Out of the 17 cases, 12 saw prototypes advanced due to the urgent pressure of an active or imminent war, including the panic of the early nuclear arms race. Today, the DoD has the goal of achieving disruptive advances more proactively, without needing the urgency of war to sustain an innovation mind-set.

A military champion able to advocate for a new technology and defend it from skeptics or competing priorities was important to getting many of the technologies beyond the prototype stage. The dictatorial nature of the Third Reich and the power of personal patronage by its top leaders may have contributed to Germany's surge of radical innovation in missiles and jets during World War II. More recent successes have seen military champions lobby aggressively for innovations they believed deserved support, such as Air Force Col. Joe Davis, the Vice Commander of the Armament Development and Test Center at Eglin AFB in the 1960s, who championed the laser-guided bomb prototypes developed by Texas Instruments until they became the Paveway series of precision-guided munitions (Spires, 2005).

In some cases, the military value of a concept was already accepted, at least within a critical constituency, and success came when a suitably mature prototype finally appeared. This "tipping point" effect was seen, for instance, with the submarine and with night vision, both of which excited some military leaders long before the technology developers were ready to realize their hopes.

Lastly, some prototypes were advanced to operational use without widespread buy-in because they were adopted within specialized communities, such as intelligence, or as part of a special program. While this made it easier to move forward quickly, it carried the risk of seeing support evaporate when the special program ended. This contributed, for instance, to the 20-year hiatus in operational reconnaissance drones following the end of the Firebee missions in Vietnam, which had been driven forward under the military intelligence community's Big Safari authority. It was only when a later generation of drones was put in the service of field commanders in the 1990s that widespread institutional support materialized within the military services.

In summary, institutional support for carrying a successful prototype into advanced development is the key hurdle at this stage, and is critical to developing the complementary DOTmLPF-P advances needed to convert the technology into a military capability. A compelling demonstration of efficacy before military stakeholders can be powerful in aligning support, especially for bottom-up innovations without a built-in constituency. Otherwise, a champion, either an individual or an organization, must effectively advocate for a disruptive innovation and protect it from overly conservative operational or budgetary forces until it has built a constituency. Means must be established of doing this in peacetime as effectively as in time of conflict.

Additional Enabling Practices

The historical case studies reveal some underlying features that may seem surprising to present-day military research and development (R&D) leaders:

- Remarkable flexibility in quickly allocating or reprogramming funds to support a new innovation;
- An open, peer/collaborator relationship between military and industry technologists; and
- A distinct, intermediate, low-volume procurement step between a successful prototype demonstration and initiation of a major acquisition program.

While some of these may seem risky in the light of current practices, they served to lower the hurdles that inhibit military innovation. They should factor into the design of future DoD experimentation and prototyping practices.

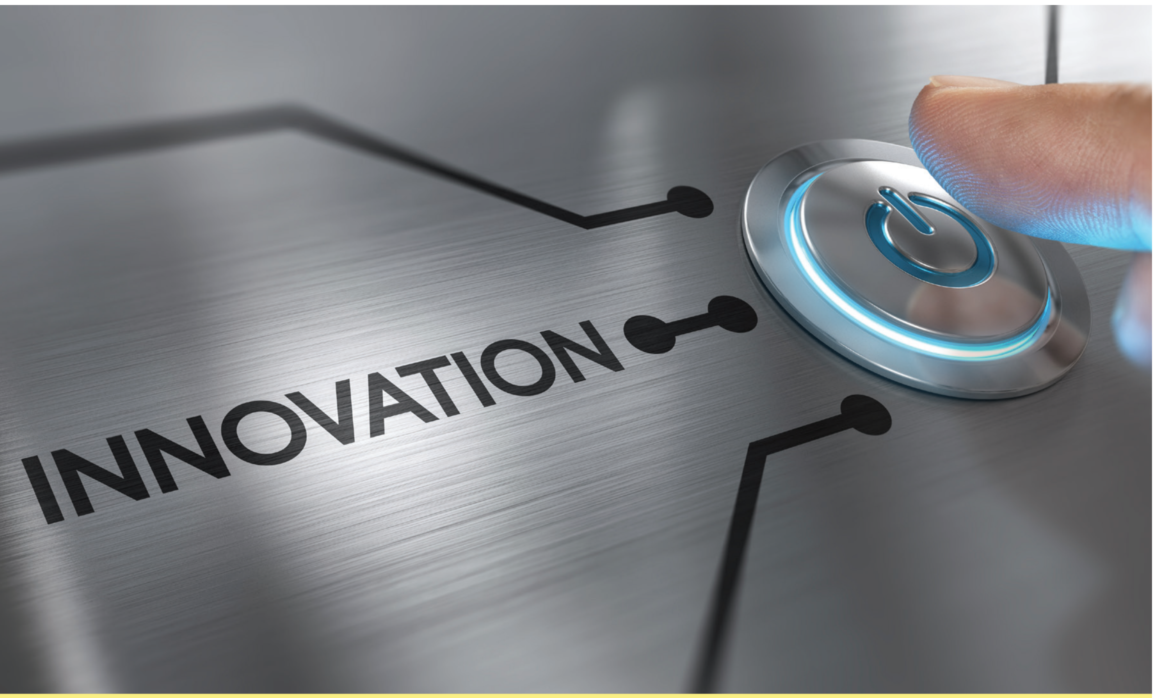
Analysis of the DoD's Experimentation and Prototyping Programs

The six DoD experimentation and prototyping programs were built in parallel, but with limited insight into one another's practices. This structured analysis will help senior DoD leaders compare and contrast the approaches taken by each, identify leading practices that can be shared and leveraged across them, and assess how the programs address the success factors identified previously.

Scope

The focus is on the six programs highlighted at the beginning of this article (Table 1), established or enhanced in parallel with BBP 3.0 and/or the DII. Experimentation and prototyping activities of various kinds also occur within the military science and technology (S&T) laboratories and warfare centers, within major acquisition programs, and within the various offices of the Defense Advanced Research Projects Agency (DARPA). This analysis does not address them nor efforts conducted entirely within industry or academia.

Interviews were conducted with senior leaders and staff directly associated with each program. A structured data collection guide was used for all interviews. This enabled a consistent and comprehensive picture of each program, and helped in drawing comparisons and contrasts between them. A total of 11 interviews were conducted covering the five non-Air Force programs. The same data collection guide was completed for the Air Force program using informal discussions with many Air Force staff. The data were supplemented by written briefings and other materials documenting program structure and processes that were collected from the various offices.



Program Structure and Approach

Some of the military services and DoD offices built more unified programs, while others distributed their increased experimentation and prototyping across multiple areas of effort. A brief description of each program and its emphasis follows.

U.S. Army: Technology Maturation Initiative (TMI), along with ongoing support to Army Expeditionary Warrior Experiment (AEWE) and other activities. The Army established the TMI under the management of the Office of the Deputy Assistant Secretary of the Army for Research and Technology, DASA(R&T), in 2012 to facilitate expanded experimentation and prototyping outside of Army acquisition programs. Recent BBP 3.0/DII effort has focused on expanding TMI and older innovation activities such as the AEWE, which is an annual live experiment conducted by the U.S. Army Training and Doctrine Command (TRADOC) and the U.S. Army Maneuver Center of Excellence (MCoE) that puts prototypes, submitted via an open proposal process, into the hands of soldiers for evaluation, feedback, and potential Army acquisition action.

Department of the Navy: Office of Rapid Prototyping, Experimentation and Demonstration (RPED). The RPED office was established in 2015 to augment Naval experimentation and prototyping activities, which were previously tied to major acquisition programs or S&T. Focused on post-S&T, but pre-Major Defense Acquisition Program concepts, RPED attempts to address both urgent capability needs submitted by the fleet and longer term challenges identified through an annual cross-Navy deliberative process. Administratively, RPED's structure is similar to that of a major acquisition program, managed out of the Office of the Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation, DASN(RDT&E).

U.S. Marine Corps: Participation in RPED, plus ongoing support to Marine Corps Warfighting Laboratory (MCWL). As part of the Department of the Navy, the Marine Corps can participate in RPED, submitting its needs and challenges in competition with those of the Navy. But it also operates its own experimentation and prototyping capabilities centered on the MCWL, which emphasizes lean, "bottom-up" innovation driven by and for Marines. The MCWL is part of the Marine Corps Combat Development Command, which also oversees Marine training and doctrine. With the MCWL responsible for both technical prototype efforts and the development of future warfighting doctrine, concepts of operation may be developed in coordination with new technical advances.

U.S. Air Force: Strategic Development Planning and Experimentation Directorate (SDPE) and related Development Planning activities. The Air Force launched a strategic approach to prototyping and experimentation in 2016 under the banner of Development Planning, focused on executing coordinated, cross-functional campaigns of related experimentation and prototyping efforts to explore emerging technology areas and inform the development of future Air Force capabilities and acquisition programs. The construct aims to address the range of DOTmLPF-P aspects, and establishes several cross-Air Force governance bodies and working teams with program management provided by the SDPE office, which is administered as an independent Directorate of the Air Force Research Laboratory (AFRL) reporting directly to the Commander of Air Force Materiel Command (AFMC).

Strategic Capabilities Office (SCO). Established in 2012, SCO conducts demonstrations of novel operational concepts, focusing on innovative uses of off-the-shelf technologies that can provide transformative new capabilities. Focusing on joint/inter-Service challenges, the demonstrations aim for rapid transitions to joint Combatant Commands and other operational customers, who are responsible for all additional DOTmLPF-P considerations. Independent of the military services and reporting directly to the USD(AT&L)—potentially to the USD(R&E) in the near future—SCO gives its program managers the autonomy to develop novel approaches in coordination with senior DoD thought leaders and potential military users. SCO's portfolio has grown rapidly in response to the DII and BBP 3.0.

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Office of the Deputy Assistant Secretary of Defense, Emerging Capability and Prototyping. Following announcement of the DII and BBP 3.0, the USD(AT&L) converted its combat support-focused Rapid Fielding Office to create the Deputy Assistant Secretary of Defense, Emerging Capability and Prototyping, DASD(EC&P) office. Aiming for a proactive, multi-Service/joint perspective, it invests in emerging capabilities that individual military services may not be ready to embrace. The office manages several categories of projects including Emerging Capability Technology Demonstrations, Joint Concept Technology Demonstrations, Quick Reaction Special Projects, and Foreign Comparative Tests. All of these have slightly different purposes and authorities, but provide DASD(EC&P) with several alternative mechanisms to support a given technology.

The structure and approach of each of the six programs is summarized in Table 3. The descriptions are aligned using 10 consistent dimensions to facilitate comparison and contrast between them.

Comparisons and Contrasts

Many differences exist between the six programs, starting with their relative philosophies of how to apply experimentation and prototyping to defense innovation. The Figure qualitatively illustrates the programs' relative areas of effort along two dimensions. The horizontal axis corresponds to the origin of the innovations the programs address, ranging from bottom-up (emergent and unexpected) to top-down (in response to a deliberate strategic initiative). The vertical axis corresponds to the intended outputs, which drive the scope of program activity. This ranges from technically focused proof-of-concept demonstration or prototyping to more comprehensive experimentation, which may involve more deliberate and comprehensive exploration of many DOTmLPF-P dimensions, and may not necessarily involve construction of new hardware or software. In terms of the historical case studies, activities closer to the prototyping end of the axis are oriented toward advancing an innovation along the first part of the path, from idea to prototype. Those closer to the experimentation end are oriented toward developing the complete set of data and supporting innovations to take a concept from prototype toward a fieldable capability. Note that the areas shown on the Figure are approximate, and some specific projects within each program may be exceptions.

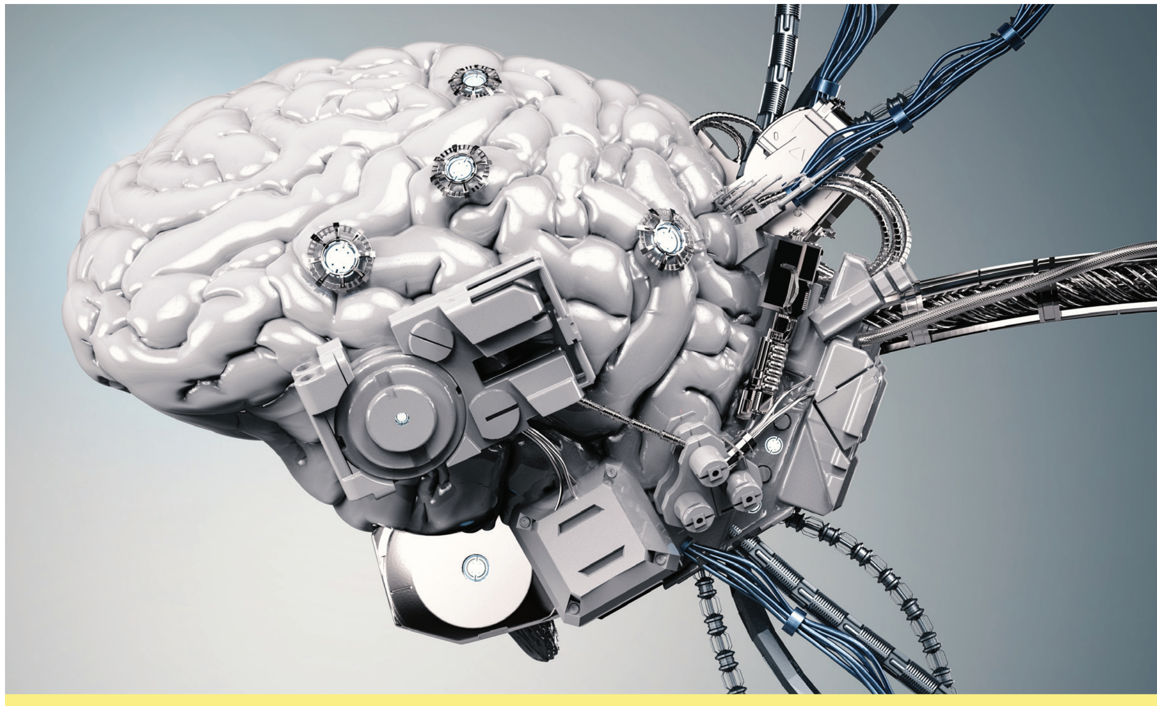


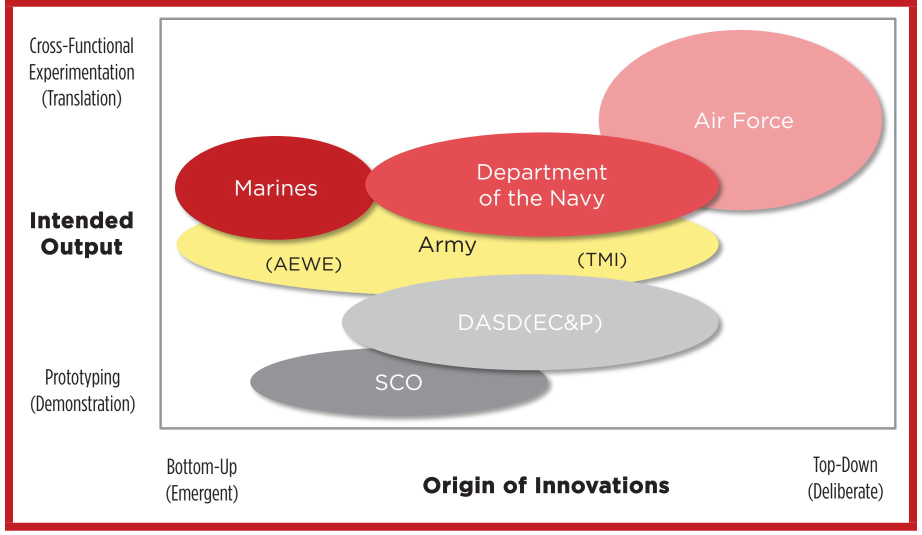
TABLE 3. COMPARATIVE STRUCTURE AND APPROACH OF DOD EXPERIMENTATION AND PROTOTYPING INITIATIVES

	U.S. Army[a]		Department of the Navy	U.S. Marine Corps	U.S. Air Force	Strategic Capabilities Office (SCO)	DASD Emerging Capability & Prototyping
	TMI	AEWE					
Organizational Location	Office of DASA(R&T)	Army Training and Doctrine Command (TRADOC) - ARCIC	Office of DASN(RDT&E)	Marine Corps Warfighting Laboratory (MCWL), under Marine Corps Combat Development Command	Air Force Materiel Command with oversight from SAF/AQR	Independent DoD office co-located with DARPA	First established under DASD(R&E)—potential reorganization under USD(R&E) in near future
Origin of Innovation Areas	DASA(R&T), in coordination with Executive Steering Group	Any proposal relevant to one of 20 Army Warfighting Challenges	Interdisciplinary Fleet Engagement Workshops, or urgent fleet requirements	Defined by MCWL against any of 14 Warfighting Challenges	Long-term strategic needs as assessed by senior, cross-Air Force Capability Development Council (CDC)	Discussions with COCOMs and other DoD leaders, and events such as PACOM Operational Exchange Meeting (OEM)	Focus Areas defined from broad DoD challenges and input from COCOMs, revised by USD(R&E) and technical experts
Origin of Specific Concepts	Army Labs in coordination with DASA(R&T) PMs and/or TRADOC	Open call for proposals to demonstrate prototypes	Workshops engaging Naval operators and the Labs and Warfare Centers	MCWL PMs and Marines, both enlisted and officer	Cross-functional Enterprise Capability Collaboration Teams, or ECCTs	SCO program managers, in coordination with military stakeholders	Annual call for proposals; winners selected by tech assessment panels
Funding Model	BA-4[b] accountwith flexible programming	Base funding for annual event	BA-4 account	BA-3 account; seeking to add BA-4 account as well	BA-4 account	BA-4 account; all programs funded outside the POM via annual Issue Paper process	BA-3 account; often with co-funding from one of the Services
Contract Mechanisms	Various, including Other Transaction Authorities(OTA), often via ARDEC at Picatinny Arsenal	Various contract types to fund follow-on activities for promising concepts	Contract vehicles within Naval Labs, Systems Commands, and Warfare Centers	Most contracting is done by partner organizations, e.g., ONR, DARPA	New solicitations, plus use of contract vehicles within Air Force Research Lab (AFRL)	Existing contract vehicles plus BAA; contracting via Army	Contracting done by partner agencies, including use of OTAs
Technical Management Location	DASA(R&T) PMs and Army Labs; each program co-led by acquisition PEO/PM	Army Maneuver Center of Excellence (MCoE)	Naval Labs or Warfare Centers	Outside partners e.g. Naval Labs, DARPA, or industry	Varies, as coordinated by new strategic office under AFRL	SCO PMs, with input from military stakeholders	Proposers, and assistance by DoD UARCs, FFRDCs
Evaluation Events	Varies by innovation area	Annual open-call event	Ad hoc events "in the fleet" with operators; Advanced Naval Technology Exercises (ANTX)	Evaluations with active Marine units, including the new Marine Experimental Battalion	Broad campaigns, including simulation, analytics, prototyping, experimentation	Varies by nature of demonstration	Tailored to category of effort (ECTD, JCTD, QRSP, FCT)
Evaluation Venues	Varies	Fort Benning, GA	Leverages fleet exercises such as RIMPAC	Leverages MAGTF Integrated Experiment (MIX), RIMPAC, etc.	Campaign-dependent; leverages AF facilities such as White Sands Missile Range	Leverages military exercises and venues, e.g., RIMPAC, Valiant Shield	Realistic environments often leveraging exercises, and UARC and FFRDC venues
Evaluation Outputs	Reports assessed by Army major program PMs	Feedback from infantry soldiers	Published assessment reports (may be classified)	Reports inform acquisition program decisions and doctrine development	Coordinated Multi-domain Flight Plans encompassing DOTmLPF-P spectrum	Varies; goal is to prove a novel operational concept and reduce perceived risks	Varies by program category
Transition Paths	Up-front TTA required with Army customer; Army Battle Labs as facilitating partners	Roundtable among Army organizations at end of each event to assign ownership and next steps for all top-rated concepts	Main customer is the fleet organization that generated the requirement; Warfighting Development Centers as facilitating partners	MCWL recommends successful concepts to Combat Development Division for advanced development and acquisition	Flight Plans define the roadmap for success including acquisition investments, supporting activities by S&T labs, MAJCOMs, etc.	Goal is to transition immediately to the COCOMs or other customers with the motivating need; customer responsible for all DOTmLPF-P aspects	Independence from Service acquisition emphasizes COCOMs as key partners; DASD(EC&P) drives process to encourage adoption and supporting activities

Note. AEWE = Army Expeditionary Warrior Experiment; AF = Air Force; ARDEC = U.S. Army Armament Research, Development and Engineering Center; ASD(R&E) = Assistant Secretary of Defense for Research and Engineering; COCOMs = Combatant Commands; DARPA= Defense Advanced Research Projects Agency; DASA(R&T) = Deputy Assistant Secretary of the Army for Research and Technology; DASD = Deputy Assistant Secretary of Defense; DASD(EC&P) = Deputy Assistant Secretary of Defense, Emerging Capability and Prototyping; DASN(RDT&E) = Deputy Assistant Secretary of the Navy for Research, Development, Test and Evaluation; DoD-UARCs = Department of Defense–University-Affiliated Research Centers; DOTmLPF-P = Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities-Policy; ECTD = Emerging Capabilities Technology Development; FCT = Foreign Comparative Testing; FFRDC = Federally Funded Research and Development Center; JCTD = Joint Capability Technology Demonstration; MAGTF = Marine Air-Ground Task Force; MAJCOM = Major Command; MCWL = Marine Corps Warfighting Laboratory; ONR = Office of Naval Research; PACOM = U.S. Pacific Command; PEO/PM = Program Executive Officer/Program Manager; PMs = Program Managers; POM = Program Objective Memorandum; QRSP = Quick Reaction Special Projects; RIMPAC = Rim of the Pacific (Exercise); S&T = Science and Technology; SAF/AQR = Deputy Assistant Secretary of the Air Force/Science, Technology, and Engineering; TMI = Technology Maturation Initiative; TRADOC-ARCIC = U.S. Army Training and Doctrine Command-Army Capabilities Integration Center; TTA = Technology Transition Agreement.

[a]Other Army activities that are often relevant to this space include Army Warfighting Assessments, which are individually structured and budgeted experimentation projects, S&T Adaptive Red Teaming, and TRADOC-ARCIC Live Prototyping Assessments (ALPA), which are S&T-focused experiments. Similar other activities exist for the other Services. [b]Budget Activity-3 (BA-3) and BA-4 accounts are budget categories used in the DoD acquisition budget. BA-3 funds are allocated to Advanced Technology Development; BA-4 funds are allocated to Advanced Component Development and Prototypes.

FIGURE. QUALITATIVE COMPARISON OF RELATIVE AREAS OF EFFORT FOR SIX NEW PROGRAMS



Note. AEWE = Army Expeditionary Warrior Experiment; DASD(EC&P) = Deputy Assistant Secretary of Defense, Emerging Capability and Prototyping; SCO = Strategic Capabilities Office; TMI = Technology Maturation Initiative.

The Air Force's approach is the most oriented toward top-down strategic challenges. Its activity is organized into campaigns of mutually related experimentation and prototyping projects to explore questions of strategic importance such as how to provide future close air support or how to apply directed energy weapons, such as lasers and electromagnetic beams, in future air combat. It involves stakeholders across the Service, and its outputs include cross-functional "flight plans" that address the spectrum of measures needed to bring potential new capabilities to the field.

The Marine Corps and Army AEWE programs, by contrast, are the most welcoming of bottom-up innovations, with processes designed to accept an unheralded prototype or concept from a nontraditional source, to give it a military demonstration, and to provide a pathway for it to affect military capabilities.

While the Air Force is the most oriented toward comprehensive experimentation, the SCO is the most oriented toward quick-hit demonstrations, coming up with its own ideas and showing proof of principle in brief, but dramatic field tests, then transitioning interesting concepts to Combatant Commands or military services for all subsequent experimentation and supporting innovation.

The other programs take intermediate approaches. Notably, all six programs are limited in their areas of effort, and none address all the areas of need. Having limited resources and charters, they serve as patches to cover gaps in existing technology development and acquisition systems. However, they offer examples of practices that could be more widely deployed as part of a broader DoD approach to accelerating defense innovation.

Leading Practices

The six programs are newly constituted, and it may be years before comparisons can be made regarding the success of each. However, each of the programs has well-designed practices that could be emulated by the others or included in the design of larger DoD innovation initiatives being developed under USD(R&E). Notable examples are summarized in Table 4. The programs with the most specialized areas of effort, described in the previous section, have the most robust practices specific to those areas. For instance, the Army's AEWE provides a good model for how to provide an "open door" for unexpected, bottom-up defense innovations.

TABLE 4. EXAMPLES OF LEADING PRACTICES AMONG DOD EXPERIMENTATION AND PROTOTYPING INITIATIVES

Operational Practice	Leading Example(s)
Bottom-up/open innovation	• Army Expeditionary Warrior Experiment (AEWE) • Marine Corps Warfighting Laboratory (MCWL)
Use of innovative contracting authorities	U.S. Army Armaments Research, Development and Engineering Center (ARDEC) Contracting Office, Picatinny Arsenal
Engagement of the DoD labs	U.S. Navy Office of Rapid Prototyping, Experimentation and Demonstration (RPED) use of Navy Research and Development centers to drive the technical solution for each prototyping project
Ability to protect flexibility in BA-4 programming	U.S. Army Technology Maturation Initiative (TMI)
Use of BA-3 for advanced prototyping	• Deputy Assistant Secretary of Defense, Emerging Capability and Prototyping, DASD(EC&P) • MCWL
Institutional connection to nonmateriel aspects of innovation	• U.S. Army Training and Doctrine Command-Army Capabilities Integration Center (TRADOC-ARCIC) • MCWL
Risk-accepting culture of innovation	Strategic Capabilities Office (SCO)
Ability to conduct both large and small innovation project types	DASD(EC&P)
Top-down/transformational cross-functional innovation	U.S. Air Force Strategic Development Planning and Experimentation (SDPE)

Note. Budget Activity-3 (BA-3) and BA-4 accounts are products of the Naval Research Advisory Committee (NRAC) Panel on Budget Activity. BA-3 funds are allocated to Advanced Technology Development; BA-4 funds are allocated to Advanced Component Development and Prototypes.

In addition, rigid DoD financing and contracting processes have been barriers faced by all recent DoD innovation programs. The six programs have explored unique approaches to getting the necessary flexibility and agility to move quickly. Some of these could be adopted more broadly.

Regarding financing, most DoD prototyping activities are meant to use BA-4 (Advanced Component Development and Prototype) funds, which are explicitly intended for post-S&T, pre-Acquisition program activities like these. However, in practice, almost all BA-4 funds are controlled by major acquisition programs. More critically, they have to be programmed with detailed spending plans at least 3 years in advance, like major acquisition program funds, making it very difficult to respond to fast-moving innovation opportunities.

The Army's TMI has successfully worked with appropriators in Congress to gradually gain added flexibility for its BA-4 funding line, enabling it to direct funding to the projects that emerge through its annual selection process. SCO has taken the innovative approach of funding all of its projects outside the normal budget cycle using the annual Issue Papers process, meant to enable Congress to add money to cover unfunded needs, which allows it to request BA-4 funds less than 1 year in advance. This has been a successful strategy for SCO thus far, allowing the office to expand its portfolio of active projects well beyond the scale of the other initiatives. The Marine Corps and the DASD(EC&P) office take the alternative approach of funding their projects using BA-3 (Advanced Technology Development) funding, which is a class of S&T funding typically used for earlier-stage S&T programs and which doesn't require detailed spending plans.

"No single program can address all needs, but the increasing urgency to accelerate innovation within the DoD—most recently shown by the creation of USD(R&E) as the third most powerful office in OSD—suggests the time for such a rethink has arrived.

In search of agile and flexible contracting processes, most of the programs outsource their contracting to military service S&T labs, which can issue task orders under pre-existing contract vehicles such as Indefinite Delivery, Indefinite Quantity (IDIQ) contracts. Such contracts can then speed new contracting actions because the eligible awardees have already been selected through an earlier competition. However, this route may restrict the potential awardees to those already on the contract vehicle, who are usually experienced defense contractors. Among the Service labs, the U.S. Army Armaments Research Development and Engineering Center (ARDEC) at Picatinny Arsenal was noted by multiple program leaders as a pioneer in the use of innovative contracting authorities, many of which haven't been heavily utilized by other military organizations. The SCO uses ARDEC as its designated contracting office and is also initiating a Broad Agency Announcement—a contracting mechanism that provides a degree of flexibility and has traditionally been used for S&T funds by DARPA and defense labs.

Recommendations for Future Defense Innovation

These six programs are each limited in scope and resources, and were established more to address shortfalls in standard military development and acquisition processes than as parts of a comprehensive institutional rethink of how military innovation is promoted. No single program can address all needs, but the increasing urgency to accelerate innovation within the DoD—most recently shown by the creation of USD(R&E) as the third most powerful office in OSD—suggests the time for such a rethink has arrived. The results of this study suggest specific elements that USD(R&E) and other senior leaders should incorporate when strengthening or building new experimentation and prototyping activities to promote disruptive defense innovation:

1. **Address both the early-stage translation of ideas into working prototypes and the subsequent stage of advancing those prototypes toward fielded capability.** The success factors for each stage are different, and process failures anywhere along the development path can kill a potentially valuable disruptive innovation, so a successful approach must address the entire path.

2. **Provide distinct pathways for both unexpected, bottom-up innovation and strategically driven, top-down innovation.** They require different approaches, particularly in the early stage.

3. **Provide options for innovators to develop full working prototypes, and prove their potential in demonstrations to promote bottom-up innovation.** Senior management should minimize the need for innovators to convince military gatekeepers of the potential value of an innovation before developing a prototype. Private R&D can be leveraged to a greater extent if there is an opportunity for a return on investment for a successful demonstration. While limited in scope, the Army's AEWE is a useful model to emulate.

4. **Use organized top-down initiatives to drive those strategic technology innovations that require broad-based institutional experimentation and transformation.** As with Churchill's Landships Committee, the rise of strategic nuclear weapons and the Army's "own the night" initiative—ensuring a strong center of vision, sponsorship, funding authority, and alignment of cross-functional efforts—can foster the necessary connections to solidify broad ownership of a disruptive technology.

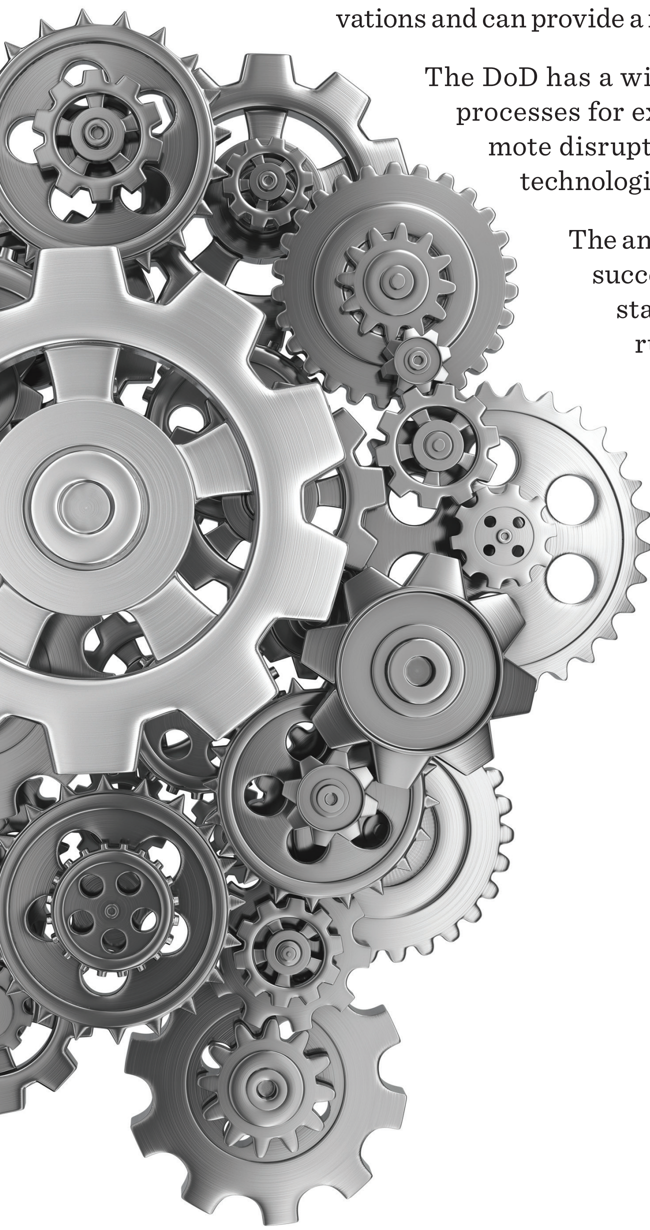
5. **Allow multiple options for sponsorship.** Disruptive innovations, unlike incremental innovations, lack existing constituencies and DOTmLPF-P support, and can be threatening to established stakeholders. For instance, new authorities can be put in place to enable specialized operational communities to fund and protect promising innovations that the broader military may not be ready to support.

6. **Arrange for demonstrations in high-visibility forums, whether physical or virtual.** This can help operational champions, gatekeepers, and key stakeholders, including those within the nontechnology DOTmLPF-P functions, to rapidly align support behind a successful concept.

7. **Ensure that flexible and agile funding and contracting mechanisms are available for experimentation and prototyping activities.** In addition to authorizing them, ensure that a wide range of finance and contracting office personnel are trained and comfortable using them in practice.

8. **Empower a strong community of military technologists, including uniformed service members.** They are needed to cultivate a high level of contact with the external innovation market, to critically assess emerging technologies against military needs, to champion emerging innovations, and to identify when technology is approaching a militarily useful "tipping point."

9. **Modify the development process to encourage the use of an advanced prototype procurement step intermediate between a promising prototype demonstration and a full acquisition program.** The rapid procurement of a small number of advanced prototype systems and their experimental use by military units have often accelerated past disruptive innovations and can provide a return on investment for innovators.



The DoD has a window of opportunity to re-engineer its processes for experimentation and prototyping to promote disruptive innovation and secure U.S. military technological superiority.

The analysis of historical case studies identified success factors that apply to the two distinct stages of the development pathway for disruptive innovation: (a) the path from idea to fully working prototype, and (b) the subsequent path from prototype to adoption and fielded capability.

Analysis of the six recently established programs identified transferable best practices for program operations. Together, these inform concrete recommendations that senior DoD leaders can apply in the design of programs that can drive new generations of disruptive military capability to the warfighter.

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